Indian Journal of Geo Marine Sciences
Vol. 48 (01), January 2019, pp. 75-84

Evaluation of the reanalysis wind over the Indian Ocean across the seasonal reversing wind pattern

G. Udhaba Dora[1,*], R. S. Kankara[2] & K. Rasheed[3]
[1]CSIR-National Institute of Oceanography, Regional Centre, Four Bungalows, Mumbai 400 053 India.
[2]Integrated Coastal and Marine Area Management - Project Directorate (ICMAM-PD), NIOT Campus, Chennai-600100, India.
[3]Centre for Marine Living Resources and Ecology (CMLRE), Kochi - 682037, Kerala, India.
[Email: udhaba@nio.org, kankara@icmam.gov.in, rasheed@cmlre.gov.in], * corresponding author

Received 08 August 2017; revised 08 January 2018

Present study show the similarity as well as contradictory event among the four different wind data based on monthly, seasonally and annual wind pattern over Indian Ocean. All the four reanalysis wind sources exhibit almost similar trend in their annual as well as monthly average wind pattern, however there is no strong similarity at their peak condition in space and time.The statistical analysis, based on Mean Absolute Error (MAE) and correlation coefficient (R), exhibited that the ECMWF and NCMRWF wind shows comparatively good agreement with the moored buoy data than the NCEP/NCAR and NCEP/CFSR wind under the seasonal reversing wind pattern occurs across the consecutive monsoons.

[**Keywords**: NCEP/NCAR, NCEP/CFSR, ECMWF, NCMRWF, Moored buoy, Statistical analysis]

Introduction

The wind observation over global region through measurement is not only expensive but also time consuming, as well as this will create obstruction to other natural phenomena. Second option, i.e. satellite observation is also expensive. The third possiblity, i.e., based on the advanced numerical calculation is highly handy in all aspects. Nowadays, there are many sources providing wind data for understanding the local and/or global wind behaviour. However, there is some difference in their procedure to predict the wind pattern as well as in the spatio-temporal resolution. Hence, finding a realistic wind source over space and time is a primary task for interpreting wind event. In this study, the wind pattern was analysed from different sources over Indian Ocean across the seasonal reversal wind pattern that occurs along the successive monsoons (Figure 1). The summer (southwest) monsoon covers from June to September, whereas the winter (northeast) monsoon covers from October to December, and the remaining period belongs calm weather condition, which has taken as pre-monsoon[1]. Present study directly focuses on the wind pattern over the North Indian Ocean (NIO) including Arabian Sea and Bay of Bengal, where the degree of agreement among the different sources are analysed followed by a comparison with moored buoy wind records.

Materials and Methods

In this study the inter-comparison among the different wind sources was caried out during 2014 which lies in the normal global climate, i.e. neither this period belongs to the La Nina nor El Nino events which is described in a tabular form at the National Weather Service Climate Prediction Centre (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml). The four difference wind sources: The National Centers for Environmental Prediction and the National Center for Atmospheric Research (NCEP/NCAR) wind[2], the European Centre for Medium-Range Weather Forecasts (ECMWF) wind[3], the National Centers for Environmental Prediction and Climate Forecast System Reanalysis (NCEP/CFSR) wind[4], and the National Centre for Medium Range Weather Forecast (NCMRWF) wind[5] were considered in this study for sort out the best reanalysis wind sources over the Indian Ocean. Spatio-temporal resolution and the ground elevation of the forecasted wind over the selected domain are given in Table 1. The NCEP/NCAR wind data at 0.995 sigma level represents ~42 m above the ground[6], whereas the NCEP/CFSR, ECMWF and NCMRWF wind data are at 10 m from the mean sea level (MSL). In response to evaluation of reanalysis wind, the moored buoy

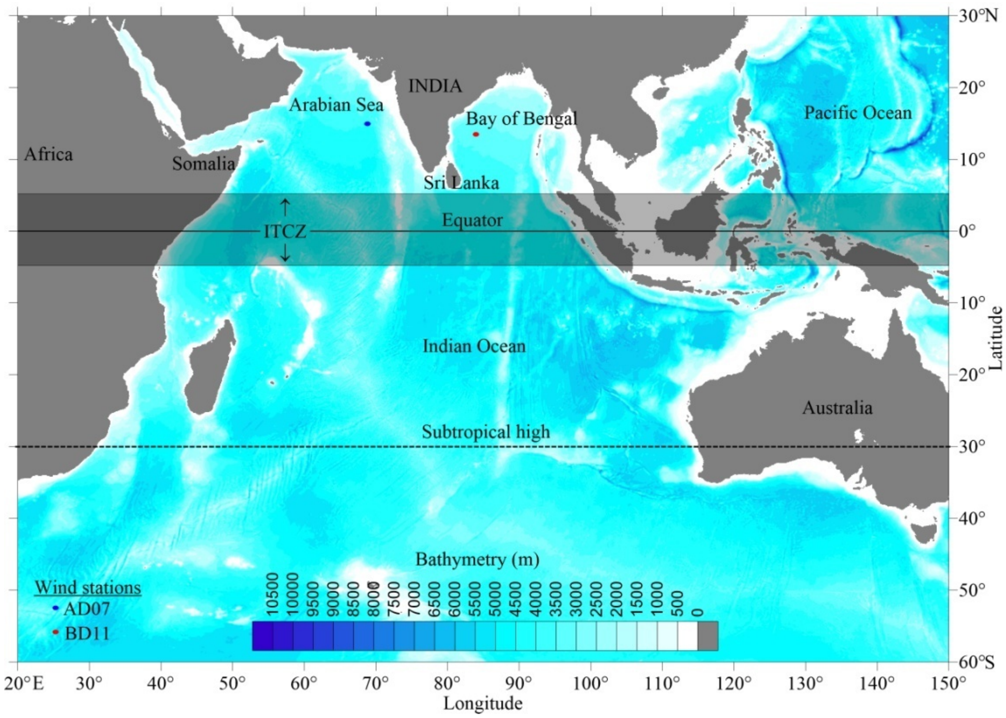

Fig. 1— Scenario for study area and the two in situ wind observation locations

Table 1 — Brief description of wind data used in this study

Source	Name	Spatial resolution (°)	Temporal resolution (hr)	Start area	End area
				Lon (°), Lat (°)	
Reanalysis wind data					
NCEP	NCEP/NCAR	2.50x2.50	6	20E,60S	150E,30N
ECMWF	ECMWF	0.75x0.75	6		
NCEP	NCEP/CFSR	0.50x0.50	1		
NCMRWF	NCMRWF	0.25x0.25	6		
Moored buoy measured wind data					
INCOIS	AD07 BD11	In situ	0.5	68.897E,15.049N 83.993E,13.484N	

measured wind was collected from INCOIS at two locations: one was in Arabian Sea and other one was in Bay of Bengal. The location of moored buoy measurement and time interval of wind data records are given in the Table 1. As the NCEP/NCAR wind was at ~42 m and the in situ wind data was at 3 m from the MSL, the both wind data was converted to 10 m elevation with respect to MSL based on the wind profile power law[7] as per Eq. (1).

$$U_Z = U_R * [Z/R]^P \quad \text{... (1)}$$

where U_Z is the wind speed to be calculated at Z elevation, U_R is the wind speed that is measured at a fixed elevation (R) and used as the reference wind speed, and P is the power law exponent and is equal to 1/7.

The meteorological convention is used for presenting direction of wind (0° for wind/wave from North, 90° for East, 180° for South, and 270° for West), while the abbreviations N, E, S, and W were used for north, east, south, and west respectively. Degree of agreement was estimated using both dimensional as well as nondimensional statistical approaches. Dimensional statistical approach was evaluated by the Mean Absolute Error (MAE) using Eq. 2. The nondimensional statistical approach was based on the Pearson's product-moment correlation coefficient (PPMCC or PCC or Pearson's r) have been referred as R. The R varies between -1 to 1, where the R^2 value close to 1 reflects perfect agreement, and the formula is presented by Eq 3.

$$\mathrm{MAE} = \overline{|x_c - x_m|} \qquad \text{... (2)}$$

$$R = \frac{\sum_{i=1}^{n}(x_m-\overline{x_m})(x_c-\overline{x_c})}{\sqrt{\sum_{i=1}^{n}(x_m-\overline{x_m})^2 \sum_{i=1}^{n}(x_c-\overline{x_c})^2}} \qquad \text{... (3)}$$

where, x_c and x_m are the calculated (simulated or modelled) and measured (observed) values respectively. The x bar ($\bar{x} = \frac{\sum_{i=1}^{n}(x)}{n}$) represents the mean value of x, where n is the number of data and $\sum_{i=1}^{n}(x)$ denotes the summation of n number of x values.

Result and Discussion

Annual sea surface wind pattern

Based on the one year data, average wind speed and resultant direction as well as extreme wind speed and respective direction was estimated at each grid over the Indian Ocean in consideration of understanding variability among the different wind sources. During 2014 over the selected domain, annual average wind speed and direction from the four sources exhibited almost similar trend even though the predicted wind are based on different grid resolutions (Figure 2A). Annual average (maximum) wind speed among the grids over the selected domain was 3.16 (8.83), 3.60 (9.94), 3.51 (10.57), and 3.58 (10.07) m/s respectively for the NCEP/NCAR, ECMWF, NCEP/CFSR and NCMRWF wind. Annual average wind direction among the grids over the selected domain was 189.6°, 189.5°, 187.8° and 185.9° respectively for the NCEP/NCAR, ECMWF, NCEP/CFSR and NCMRWF wind, while the maximum wind direction was 359° for all the wind sources. The arrow (→) represents annual resultant wind direction. The annual average wind pattern exhibited that there was no link between the wind over NIO with the wind belongs up to 40°E and beyond 120°E as well as from 30°S to 60°S. The annual average wind pattern exhibited that the southeast (SE) trade wind generated at subtropical high (horse latitude) in the southern hemisphere (30°S) was the source of the wind pattern over the NIO. The wind was strong around 16°S over the area from 42K to 45L Universal Transverse Mercator (UTM) zone. The wind was blowing towards the east coast of Africa continent and thereby turned towards north with interacting the same continent. The deviated wind again gradually turned towards right along the associated subcontinents. The wind blow path continued towards south along the western Indian subcontinent (Figure 2A). Over the equator, an interaction of the deviated wind with the SE trend wind was observed. The wind over the Inter Tropical Convergence Zone (ITCZ) over 0±5° showed an existence of comparatively low wind speed. Thereby, the resultant wind was moving towards east up to end of the Sri Lanka Island. Further, the resultant wind was deviated towards northeast along the east coast of Indian subcontinent over the Bay of Bengal. The wind pattern from the Arabian Sea to Bay of Bengal through south end of the Indian subcontinent represents the strong impact of subcontinents on the general wind patterns, whereas the general wind pattern from subtropical high (horse latitude) in the northern hemisphere (30°N) to ITCZ is northeast trade wind. The annual average wind pattern revealed that a similar wind pattern was dominating effectively to the Arabian Sea as well as Bay of Bengal.

At extreme condition of the wind at individual grids over the selected domain, the four different sources exhibited a considerable variation in the wind speed as well as respective direction (Figure 2B). Average (maximum) wind speed among the annual peak at each grids over the selected domain were 15.06 (27.57), 15.64 (53.71), 18.05 (57.98), and 17.07 (37.71) m/s respectively for the NCEP/NCAR, ECMWF, NCEP/CFSR and NCMRWF wind. Average wind direction among the annual peak at each grid over the selected domain were 203.7°, 209.6°, 208.7°, and 203.2° respectively for the NCEP/NCAR, ECMWF, NCEP/CFSR and NCMRWF wind, while the maximum wind direction was 359° for all the wind sources. Study showed comparatively high wind speed over the zone from subtropical high to polar front in the southern hemisphere (40-60°S), and also some part of the North Pacific Ocean along the eastern Asia continent.

However, there was no impact of this wind on the wind pattern over NIO. The wind direction over the NIO was almost similar in all the four sources. Among the four different sources over the Arabian Sea as well as in the Bay of Bengal, a considerable variation in the peak wind speed was observed. Over the NIO, strength of the peak wind speed in the NCEP/CFSR was high (57.98 m/s) whereas that was low (27.57 m/s) in the NCEP/NCAR wind. Further, it was observed that the wind speed greater than 30 m/s in the NCEP/CFSR over the Northern Pacific Ocean covered around 20° width along latitude as well as

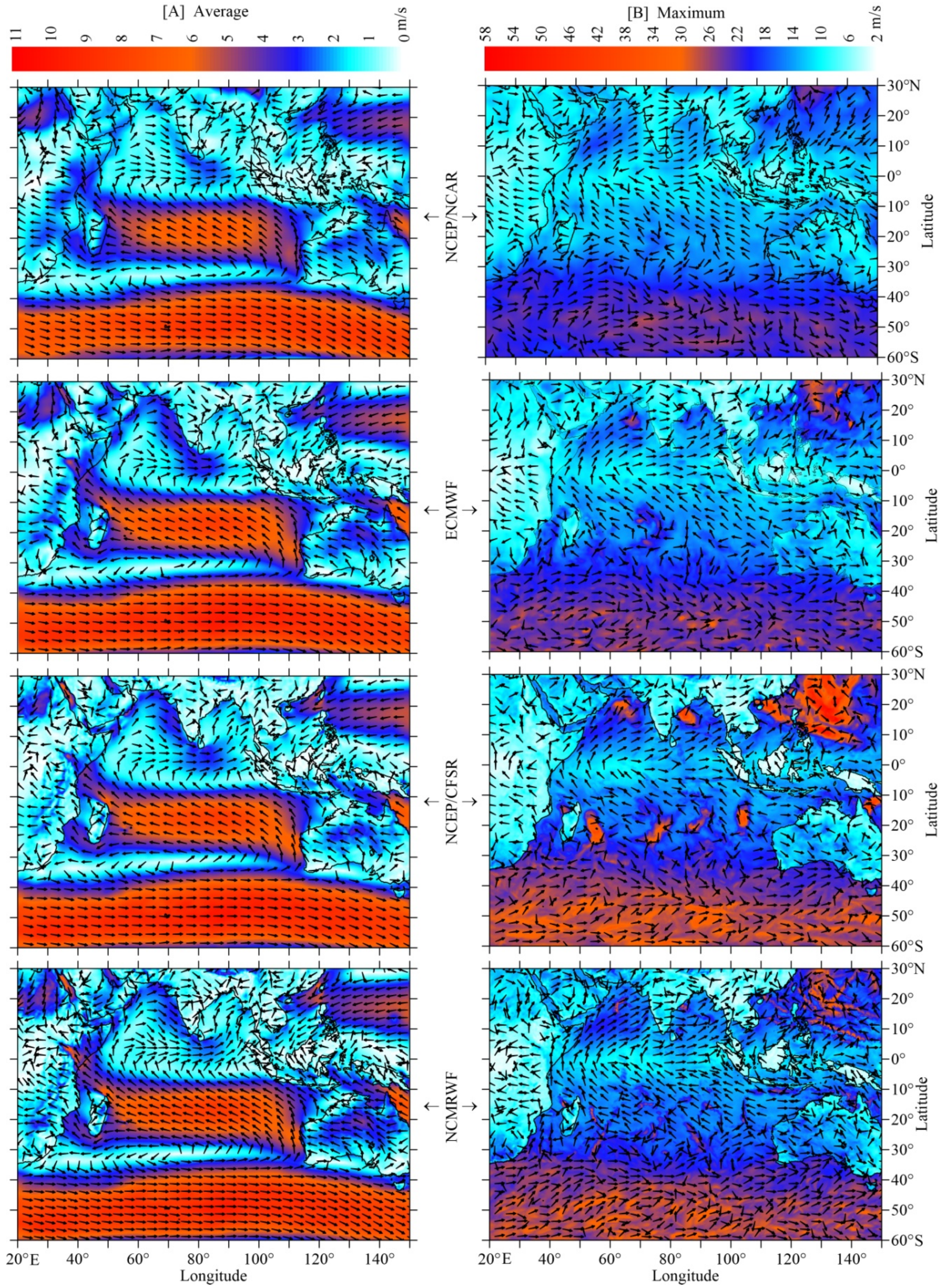

Fig. 2 — Variability in the annual [A] average and [B] maximum wind speeds and respective directions among the NCEP/NCAR, ECMWF, NCEP/CFSR, and NCMRWF sources during 2014

longitude, whereas the NCEP/NCAR showed below 30 m/s. Hence, the variation in the high wind speed between the different sources was not due to the variation of grid resolution. Further, both of the wind are from the same sources. So, the variation of wind speed might be due to the different procedures followed for wind prediction.

Monthly sea surface wind pattern

As the NIO strongly interacts with seasonal reversal wind pattern, the wind pattern among the four different sources was examined over the Indian Ocean based on their monthly average wind speed and resultant wind direction (Figure 3 & 4). The four different sources showed almost similar wind direction in each month during the year, whereas there was small variation in the wind speed. Wind speed in the NCEP/NCAR during all the months was comparatively less than that observed in the other three wind sources. The difference of wind speed was might be due to the variation of grid resolution or in the procedure followed for prediction of wind pattern.

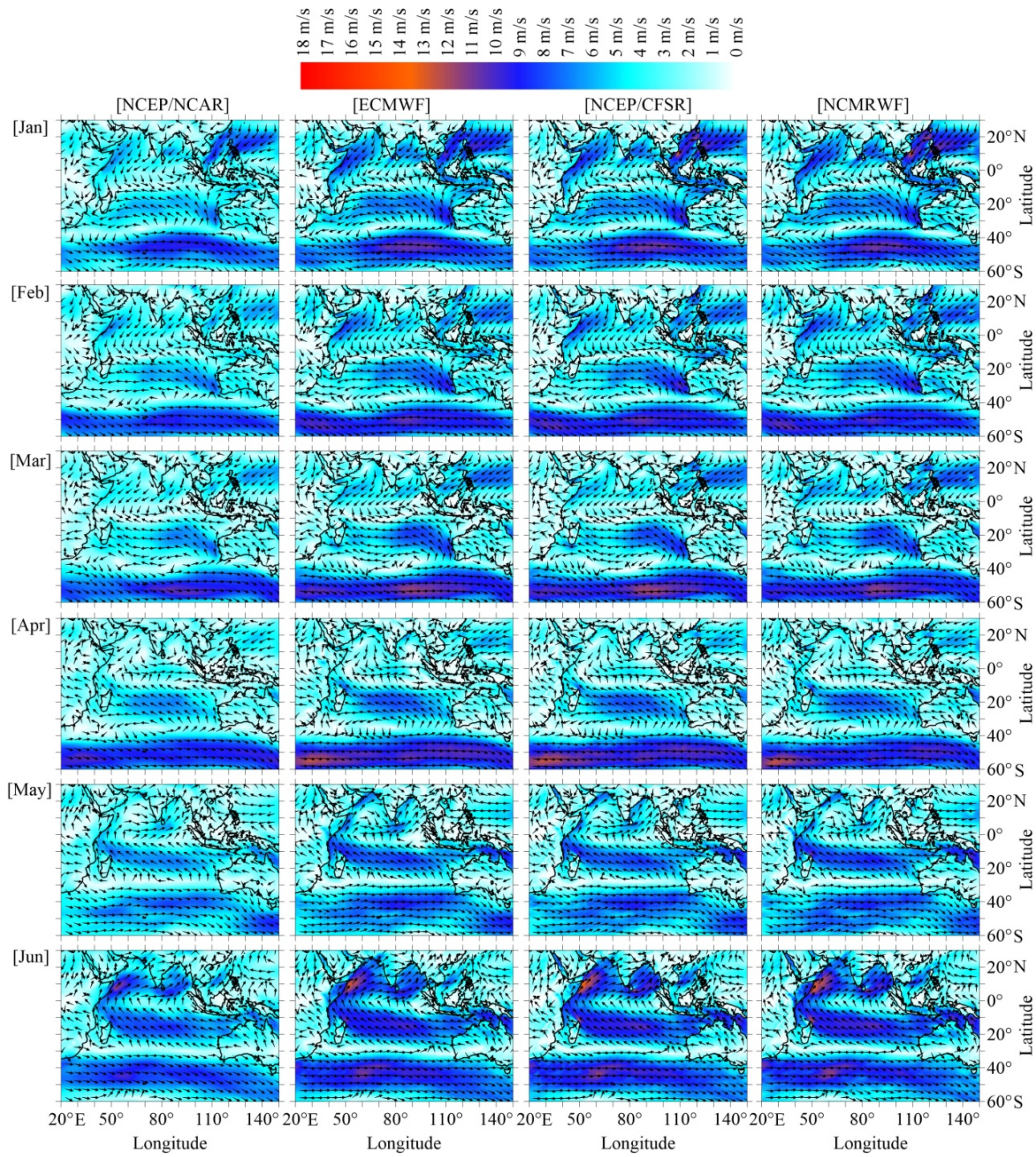

Fig. 3 — Variability in the monthly average wind speeds and directions among the NCEP/NCAR, ECMWF, NCEP/CFSR, and NCMRWF sources from January to June 2014

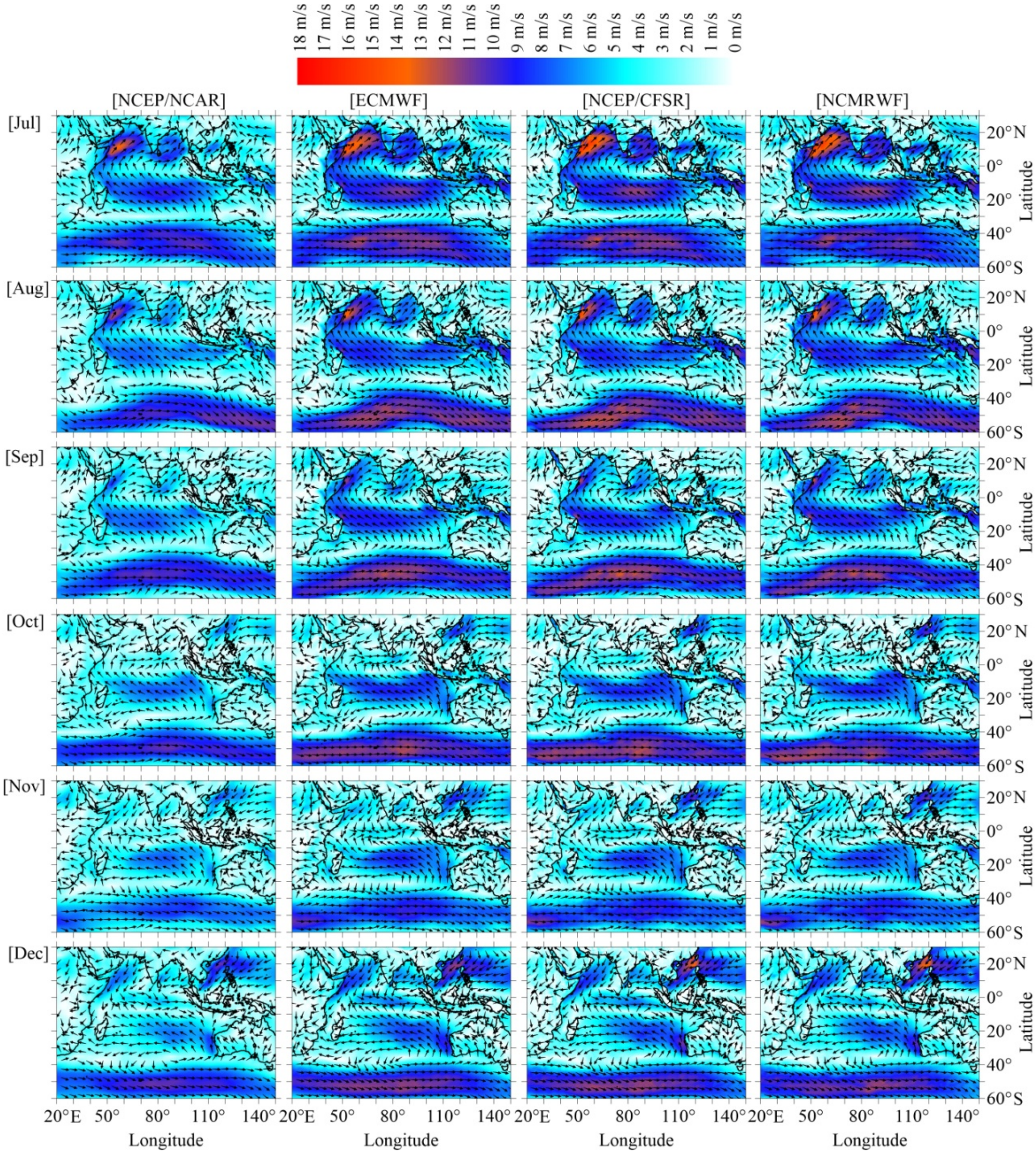

Fig. 4 — Variability in the monthly average wind speeds and directions among the NCEP/NCAR, ECMWF, NCEP/CFSR, and NCMRWF sources from July to December 2014

The wind pattern (speed and direction) was changing across the twelve months in all the four sources. From January to April, the wind from northeast (NE) was blowing over the Arabian Sea and Bay of Bengal with low intensity (< 10 m/s). An interaction of this NE wind with the SE trade wind was observed over south of the equator (0-10°S), thereby the zone was observed with low intensity wind (< 2 m/s). A gradual decrease in wind speed was observed from January to April over the Arabian Sea as well as Bay of Bengal, however, some high wind (> 10 m/s) was over some part of the South Temperate Zone (40-60°S) during March and April. During May, the wind pattern over both the Arabian Sea and Bay of Bengal turned reversely with slight increased wind speed. This reversing wind pattern exhibited that the transitional stage between the northeast and southwest winds occurred during the May. The wind pattern exhibited that the SE trade wind generated at subtropical high in the southern hemisphere (30°S) was the source of the wind pattern over the NIO across the four months from June to September. The strength of wind speed increased from June to July, thereby continuously decreased up to the end of the year. Further, study revealed that some high intensity wind were generated at the coast of Somalia during the June and existed up to September. This wind propagated towards northeast over the Arabian Sea along with the southwest (SW) wind. During October, a complex wind pattern with low wind speed was observed over the Arabian Sea as well as Bay of Bengal which reflect the transitional period while the strength of SW wind gradually decreased along with a sign of the NE wind occurrence. Further, the NE wind plays moderately over NIO, while the wind strength was gradually increased from October to December. Study exhibited very low wind speed during NE wind than that compared to SW wind over NIO. Hence, the annual average wind pattern showed a dominant role of SW wind over NIO.

Statistical observation on wind pattern

As the annual as well as monthly average wind speed and direction among the four sources were found almost similar pattern, the degree of agreement for all the reanalysis wind was examined with respect to in situ measured wind data. The wind pattern (speed and direction) from the five sources over the Arabian Sea and Bay of Bengal are presented by the time series as well as the wind rose diagram. As per the data availability, degree of agreement of the NCEP/NCAR, ECMWF, NCEP/CFSR, and NCMRWF wind with respect to the moored buoy records was evaluated based on the 6 h interval data. In the Arabian Sea, the moored buoy data was found in different direction that were blowing from north during most of the time. During summer monsoon, a considerable quantity of southwestwest (SWW, 240-270°) wind was observed in all the four reanalysis wind (Figure 5), while that

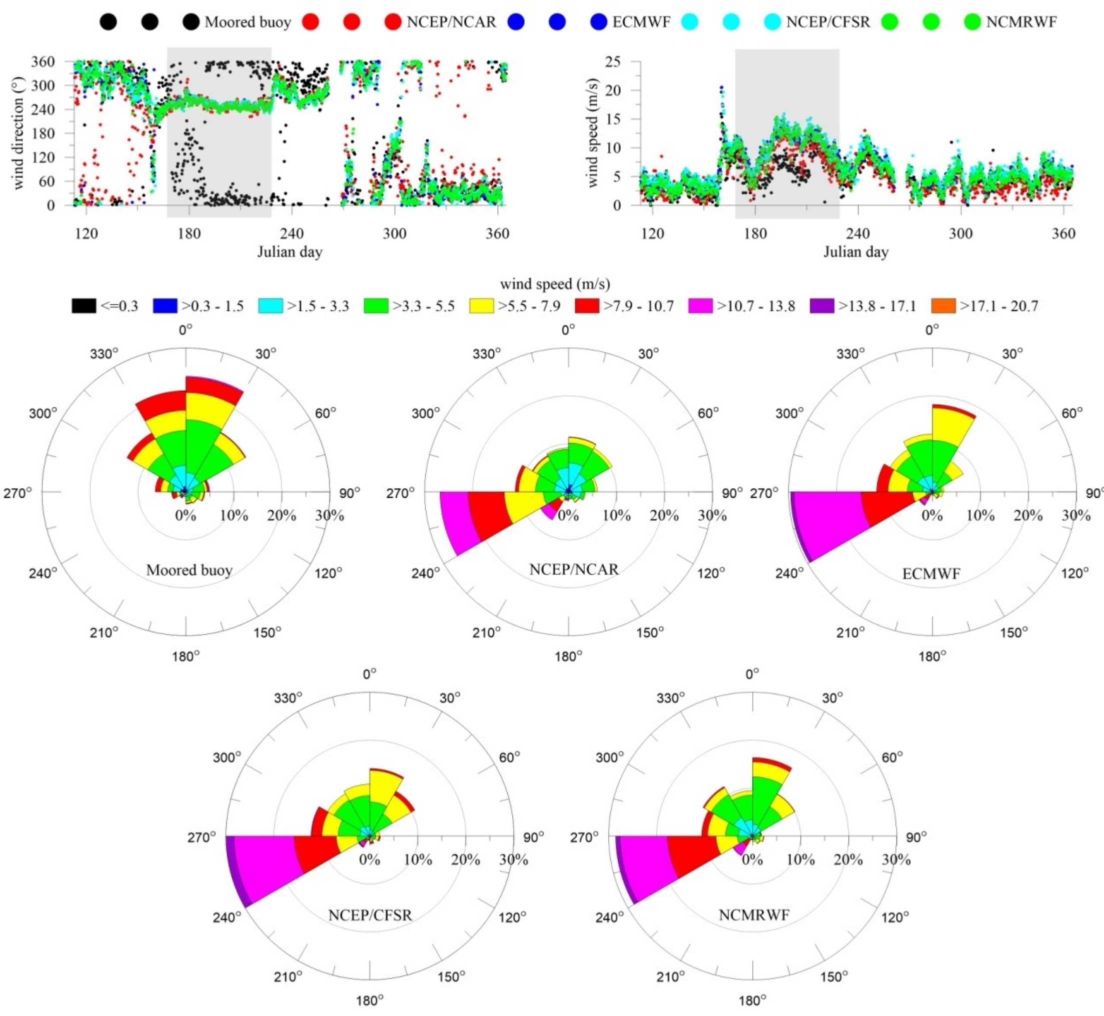

Fig. 5 — Wind pattern at specific point in the Arabian Sea from five selected sources (moored buoy, NCEP/NCAR, ECMWF, NCEP/CFSR, and NCMRWF data)

was not recorded by the moored buoy. This strong mismatch data during the summer monsoon is marked by square patch on the time series wind data. During this period, the SW or/and SWW wind usually dominates over the Arabian Sea, and hence it was considered as there was some malfunction in the instrument used for measuring wind pattern. At this point during the period of comparison, the average (maximum) of the moored buoy wind was 5.0 (19.7) m/s where the NCEP/NCAR, ECMWF, NCEP/CFSR, and NCMRWF wind showed 5.1 (13.6), 6.6 (20.5), 6.8 (19.7), and 6.1 (15.4) m/s respectively. It showed that the wind was observed up to fresh gale (17.2-20.7 m/s) condition, however due to the malfunction in the in situ observation, no further valuation of the reanalysis wind to the moored buoy wind was carried out. During the study period, the reanalysis wind showed a considerable quantity of gentle breeze (3.3-5.5 m/s), moderate breeze (5.5-7.9 m/s), fresh breeze (7.9-10.7 m/s), and strong breeze (10.7-13.8 m/s) along with few quantity of light breeze (1.5-3.3 m/s), light air (0.3-1.5 m/s) and calm (< 0.3 m/s) condition.

During the summer monsoon, all the four reanalysis wind exhibited as the SWW wind, and the wind condition was composed of moderate, fresh and strong breezes. However, the wind was blowing from a wider angle during the winter monsoon with a composition of gentle and moderate breezes. A minor variation was observed in the quantity of wind speed as well as the direction among the four reanalysis wind sources.

During the period of wind comparison over the Bay of Bengal, the reanalysis winds showed similar pattern but not exactly as that observed in the moored buoy wind data (Figure 6). At the observation point

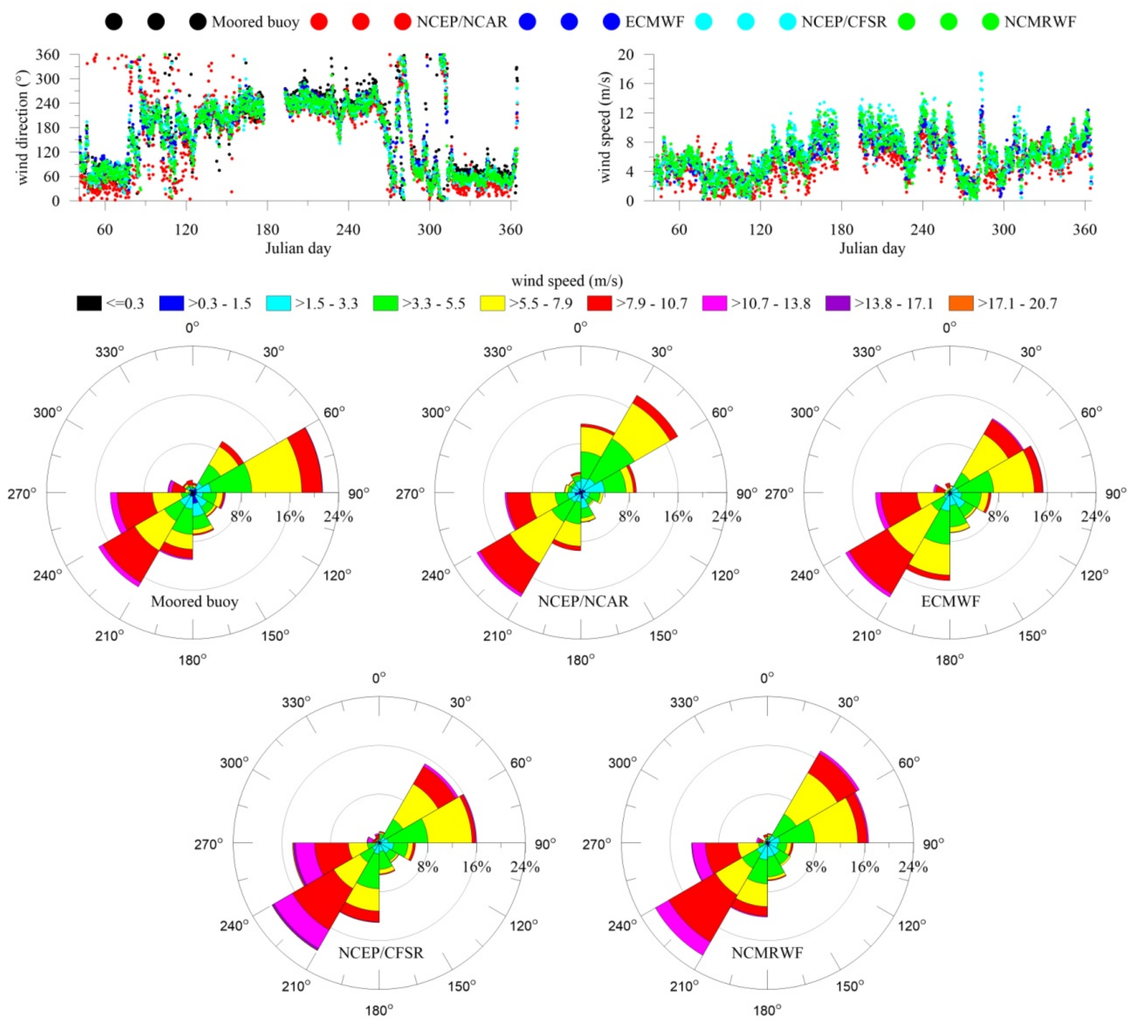

Fig. 6 — Wind pattern at specific point in the Bay of Bengal from five selected sources (moored buoy, NCEP/NCAR, ECMWF, NCEP/CFSR, and NCMRWF data).

Table 2 — Statistics on the wind speed and direction over the Bay of Bengal

Statistics (in situ vs reanalysis)	Wind speed (m/s)		Wind direction (°)	
	MAE	R (ax+b)	MAE	R (ax+b)
Moored buoy vs NCEP/NCAR	1.51	0.76 (0.66x+1.37)	41.05	0.74 (0.86x+13.15)
Moored buoy vs ECMWF	0.89	0.92 (0.80x+1.45)	18.65	0.90 (0.85x+19.63)
Moored buoy vs NCEP/CFSR	1.26	0.87 (0.93x+1.15)	23.68	0.84 (0.83x+23.49)
Moored buoy vs NCMRWF	1.04	0.89 (0.89x+1.12)	21.49	0.86 (0.84x+17.89)

during the period of comparison, the average (maximum) of moored buoy wind was 5.8 (13.8) m/s where the NCEP/NCAR, ECMWF, NCEP/CFSR, and NCMRWF wind showed 5.2 (13.1), 6.1 (12.9), 6.5 (17.5), and 6.2 (14.7) m/s respectively. It showed that the reanalysis wind was up to fresh gale condition, whereas the moored buoy wind was up to strong breeze event. All the four reanalysis winds showed that the wind during the monsoon period was dominated by the southwest (SW, 210-240°) wind along with considerable quantity of southsouthwest (SSW, 180-210°) and southwestwest (SWW, 240-270°) winds. During winter monsoon including remaining calm weather period, the NCEP/NCAR wind showed a dominant feature of northeast (NE, 30-60°) wind along with considerable quantity of northnortheast (NNE, 0-30°) and northeasteast (NEE, 60-90°) wind, whereas the ECMWF, NCEP/CFSR, as well as NCMRWF wind exhibited the occurrence of both NE and NEE winds. However, the moored buoy data showed a dominant feature of NEE wind along with some quantity of NE wind. This analysis revealed that the reanalysis winds showed good result during summer-monsoon than during winter-monsoon over the Bay of Bengal. Further, study showed that the standard deviation of wind speed in the ECMWF, NCEP/CFSR, NCMRWF data was 2.45, 2.98, and 2.80 m/s and very close to the standard deviation of wind speed in the moored buoy (2.81), whereas that was 4.00 in the NCEP/NCAR wind. The NCEP/NCAR, ECMWF, NCEP/CFSR and NCMRWF wind including moored buoy showed a mixture of wind events from most of the directions, whereas the quantity of each wind events was closer among the different sources. A good correlation was observed between the moored buoy and individual reanalysis wind in case of both wind speed and direction (Table 2). However, study showed that the correlation was stronger for the wind speed than that observed in the wind direction at all the reanalysis wind data to moored buoy wind records. The relative observation showed that the ECMWF and NCMRWF wind reflects good correlation with the moored buoy wind data than the NCEP/NCAR and NCEP/CFSR wind sources. The analysis showed that the ECMWF and NCMRWF is considerable for interpretation of wind pattern over NIO across the successive monsoons.

Conclusion

Study on the wind pattern from the four different wind sources exhibited the role of continents on the deviation of wind direction. During summer monsoon, the prevailing southeast trade wind from subtropical high (southern hemisphere) and the wind generated from the Somalia coast together impact the west coast of India. The reanalysis wind speed and direction with respect to moored buoy data revealed that the ECMWF and NCMRWF winds show comparatively high degree of agreement than the NCEP/NCAR, NCEP/CFSR winds across the seasonal reversing wind pattern over the Bay of Bengal.

Acknowledgements

The authors thank the Ministry of Earth Sciences, New Delhi, for funding the measurement program, and the Project Director, ICMAM PD, Chennai, for encouragement to carry out the study. We thank Director, ESSO-INCOIS (MoES), Hyderabad for providing the moored buoy measured wind data. We thank Director, NCMRWF (MoES), NOIDA for providing the NCMRWF reanalysis wind data. The first author thanks to Director, CSIR-National Institute of Oceanography for providing laboratory facility to analyse the available data.

References

1 IMD, Monsoon 2014 a report, Government of India, Ministry of Earth Sciences (MoES), India Meteorological Department, IMD Met. Monograph: ESSO Document No.: ESSO/IMD/Synoptic Met./01(2015)/17.

2 Kalnay et al., The NCEP/NCAR 40-year reanalysis project, Bull. Amer. Meteor. Soc., 77(1996) 437-470.

3 Dee et al., The ERA-Interim reanalysis: configuration and performance of the data assimilation system, Q. J. R. Meteorol. Soc., 137(2011) 553–597.

4 Saha, S., The NCEP Climate Forecast System Reanalysis, B. Am. Meteorol. Soc., 91(2010) 1015-1057, doi: 10.1175/2010BAMS3001.1.

5 Prasad, V.S., Mohandas, S., Gupta, M.D., Rajagopal, E.N., Dutta, S.K., Implementation of Upgraded Global Forecasting Systems (T382L64 and T574L64) at NCMRWF, NCMR/TR/5/2011 (http://www.ncmrwf.gov.in/).

6 Faucher, M., Burrows, W.R. & Pandolfo, L., Empirical-statistical reconstruction of surface marine winds along the western coast of Canada, Clim Res., 11(1999) 173–190.

7 Roland, B.S., An introduction to Boundary Layer Meteorology, Kluwer Academic Publishers, 1988, pp. 666.